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The Base Resource Allocation and Capabilities Estimator (BRACE) is an object-oriented program which simulates the important ground activities at a strategic airfield. The equipment and activities deemed important to characterizing the capabilities and limitations of airport resources are modeled as well as the aircraft and cargo flow in and out of the facility. Real time and statistical data is gathered to assess the degree to which the airfield accomplishes a desired aircraft movement. The resources and associated activities are simulated in an object-oriented architecture. The behavior of different mechanical resources are modeled independently as well as their interactions with the other resources and the customers being simulated

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FINAL REPORT

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VALIDATION OF BASE RESOURCE AND CAPABILITIES ESTIMATE: STAGE 2

December 1, 1998

INTRODUCTION

This final report is about both of the previously mentioned grants, since the purpose of both, and the personnel involved in both, were the same. The project originally started on July 1, 1996. The personnel involved were the Principal Investigator, and his graduate student, Travis Cusick. The entire project was developed in close collaboration with personnel from HQ/AMC/XPY, at Scott AFB. The project was named **BRACE SIMULATION.** Extensive tests of the simulation package which was developed as the deliverable of these grants (**at Ramstein AFB and Elmendorf AFB**) by USAF personnel resulted in very satisfactory final evaluations.

Details in addition to those listed in this report can be found at the www address: http://rodin.wustl.edu/~travis/brace.html. Thus, on the next few pages we are giving only a brief outline of our results

BRACE Simulation Overview

The Base Resource Allocation and Capabilities Estimator (BRACE) is an object-oriented program which simulates the important ground activities at a strategic airfield. The equipment and activities deemed important to characterizing the capabilities and limitations of airport resources are modeled as well as the aircraft and cargo flow in and out of the facility. Real time and statistical data is gathered to assess the degree to which the airfield accomplishes a desired aircraft movement. The resources and associated activities are simulated in an object-oriented architecture. The behavior of different mechanical resources are modeled independently as well as their interactions with the other resources and the customers being simulated.

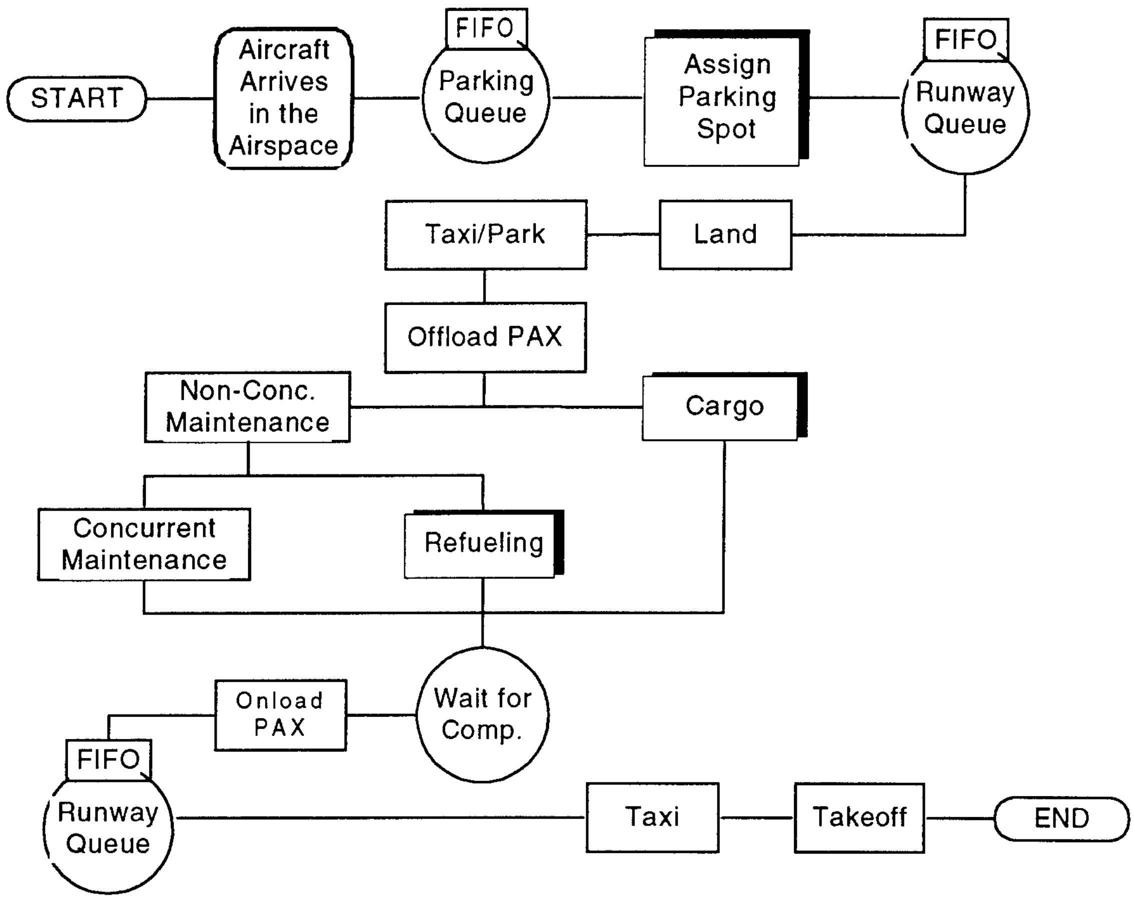
AIRCRAFT GENERATION

The stimulus which activates an airfield in a BRACE simulation is the arrival stream of aircraft which require space at the airfield as well as service from several of the airfield's resources. For conducting a particular study, the aircraft stream is defined in a file format which includes characteristics and requirements of each aircraft to be simulated. For throughput capability analysis, the aircraft arrival stream can be generated internally by BRACE with the use of user-defined random distributions and service requirement profiles.

The generation of aircraft for the simulation is generally accomplished by reading a flat file created by a spreadsheet or an airflow model such as MASS. Each line of the file contains a description of the aircraft along with the requirements of the aircraft during its visit to the airfield. The requirements include the number of passengers and amount of cargo to be unloaded from the plane and loaded back on to the plane as well as the fuel requirements and any normally scheduled maintenance. Alternatively, BRACE can be run with internally generated aircraft arrival streams. The simulation currently supports six types of aircraft (C-130, C-17, C-5, C-141, B-747, DC-8), each with a different set of definable cargo and fuel requirements. The user can specify any proportion of these six aircraft which will subsequently be chosen by use of a uniform random variable. The inter-arrival times between aircraft can be drawn from either an exponential or triangular distribution with user-specified parameters.

AIRCRAFT SERVICE SCHEDULE

Each aircraft simulated in BRACE follows a schedule of activities which require interaction between the various resources provided by the airfield. From the aircraft point of view, every activity during the simulation is analogous to waiting in a queue for an available server and subsequently obtaining service from an airfield resource. The following chart outlines the possible service requirements in the proper sequence.



When an aircraft arrives in the simulation, it enters a first in first out (FIFO) queue which assigns parking spots to aircraft. After being assigned a parking spot, the aircraft requests use of the runway and waits in a FIFO queue until the runway resource becomes available. After the aircraft lands, it taxis to the assigned parking spot where it will receive service from the airfield resources.

The removal of passengers begins after the aircraft arrives at its parking spot. This is simulated by a time delay based on a function of the number of passengers to be removed. After completion, the maintenance procedures begin. The maintenance portion of the simulation takes care of scheduled concurrent and non-concurrent maintenance as well as any non-scheduled maintenance resulting from a breakdown incident.

After the passengers have been removed, the aircraft determines whether or not a non-scheduled breakdown has occurred. The probability of a breakdown is determined from historical data depicting the rate of non-scheduled maintenance by type of aircraft. In the simulation, a uniformly distributed random variable is compared against the historical rates to determine whether or not a breakdown occurs. When an aircraft breakdown is simulated, the plane is removed from its current parking spot and moved to a maintenance facility if the time required to repair the problem is greater than a specified amount.

Normal maintenance is separated into two sets which take place sequentially. The first set must be completed before the aircraft can begin taking on fuel and is called non-concurrent maintenance. At the completion of this set of maintenance procedures, the concurrent maintenance begins as well as the refueling of the aircraft.

After the passengers have been off-loaded, the aircraft also requests the initialization of cargo related procedures. The cargo handling service consists of a series of cargo movements along with the required utilization of material handling equipment from the airfield resource pools. If the aircraft is a high-body and needs to drop off or pick up cargo, it first acquires an appropriate wide body elevator (WBEL) which raises the cargo to a height required by the plane's cargo deck. Depending upon the available resources, this can either be a dedicated lifter or a 60K loader.

If the aircraft is off-loading pallets, this service is performed first. Depending upon the number of pallets to be removed and the availability of loaders, up to three loaders are assigned to the plane to move the pallets off. If more than one loader is ready to service the plane, the loaders organize themselves in a queue behind the plane door. Upon receiving pallets, each loader travels to the docks to unload and then returns to the plane until all off-loaded pallets have been accounted for. If there is rolling stock to be removed, a time delay is used to simulate the activities of moving the rolling stock. The cargo yard is informed that the appropriate amount of rolling stock has arrived and needs to be processed.

On-loading pallets occurs in the same manner as off-loading pallets with one difference. All of the loaders that are assigned to on-load pallets wait at the plane as a group until they are completely finished and release themselves as a team. This simulates the sharing of labor between the loader operators. If rolling stock needs to be loaded onto the aircraft, a time delay is used to simulate the event and the cargo yard is informed that the rolling stock items have been moved to the aircraft. This concludes the aircraft's involvement in the cargo service phase.

The refuel operation takes care of fueling the plane and obtaining the required amount of liquid oxygen (LOX). The fueling can be done either by underground fuel hydrants or by using fuel trucks.

If the aircraft is parked at a hydrant spot, it first attempts to refuel by hydrant. This may not be possible if the maximum hydrant capacity for the airfield is currently being used. If this is the case, the aircraft enters the LOX stage of refueling and when completed, attempts to refuel by hydrant. If again, the hydrant system is cannot support this aircraft, and if there is an available fuel truck, the aircraft refuels by truck. If there are no fuel trucks available, the aircraft enters a queue for the first available hydrant capacity or fuel truck. When a resource becomes available, the aircraft retains this resource until the entire refueling requirement is satisfied. If LOX has not been completed, it is done at this time. Obtaining liquid oxygen is simulated by a time delay. It is assumed that the airfield resources do not limit the amount of aircraft obtaining liquid oxygen at any given time.

Loading passengers is the last service activity simulated. It does not begin until refueling, cargo, and all maintenance procedures have been completed. Loading passengers is simulated by a time delay which is a function of the number of passengers to on-load. After completing the on-load operation, the aircraft waits until it is time to back out of the parking spot.

The aircraft is not allowed to leave the parking spot until the time at which the taxi delay time and take-off delay time will allow it to leave the airfield at the scheduled departure time. If the aircraft is ready to back out of the parking spot but the time of day is not within the operating hours of the airfield, the aircraft waits until the next day's opening time to back out. After backing out, the aircraft informs the airfield that the parking spot has been vacated and taxis towards the runway. Upon reaching the runway waiting area, the aircraft enters the queue of aircraft requiring use of the runway.

When the runway becomes available to the aircraft, the aircraft retains the runway resource for the required amount of time. After taking off, the runway is released and the aircraft records all appropriate data before leaving the simulation.

Major Services Mathematically Defined

The equipment and activities required to provide the necessary services in a BRACE simulation have been modeled to a high precision to promote accuracy in the results. The resultant complexity of the model however leads to undesirable run times when simulating lengthy operations. For this reason it has been deemed beneficial to increase the efficiency of the model and the executable program.

By replacing sets of complex activities which are required to accomplish cargo and fuel services with equivalent time delays, the simulation can run much faster. In order to not lose accuracy in the results, the time delays used to replace simulated service activities must properly capture the actual times involved. This section describes the mathematical formulation of time delay functions that can be used to replace simulated cargo on-load and off-load procedures as well as refueling operations.

Pallet Off-Load Operation

The following notation is used to describe the parameters needed to model the operation of removing pallets from an aircraft. The goal is to derive a time delay function as seen from the aircraft's point of view.

- p_u = number of pallets to unload from plane
- n = number of k-loaders captured by plane
- k_u = number of k-loader pallet loads required to unload plane
- c_i = pallet capacity of k-loader i
- p_i = pallets on k-loader i
- t_k = one-way travel time for a k-loader
- $t_l(p_i)$ = time required to load pallets onto k-loader i
- $t_d(p_i)$ = time required for k-loader i to deliver pallets to the docks and return to plane

The aircraft is allowed to capture up to 3 k-loaders for the cargo moving operation. K-loaders are the pieces of equipment used at air bases to transport palletized cargo from the aircraft to the docks or cargo yard. If these loaders have the same capacity c, then the total number of k-loader loads required to complete the operation can be calculated exactly as $k_u = ceil(p_u / c)$. The round trip k-loader delay ($t_d(p_i)$) equals the k-loader travel time plus the time required to setup and unload the pallets at the docks. Assuming that the capacity of the docks is great enough such that the k-loaders do not have to enter a queue, this time is deterministic.

During the pallet off-load operation, the aircraft captures the k-loaders simultaneously. When the k-loaders arrive at the aircraft, they form a queue behind the plane's door to await their turn to remove pallets. Upon receiving their load of pallets, the k-loaders perform the round trip operation to the docks to deliver the pallets and then return to the aircraft if their capacity is still needed. Depending upon the number of k-loaders being utilized by the plane and the time required to deposit pallets at the docks, the plane may experience some idle time while waiting for the k-loaders to return to continue service. Taking this into account, the equation describing the total delay time experienced by the aircraft during pallet unloading (T_u^P) is as follows.

$$T_u^P = t_t + (k_u - 1) \times t_l(c) + trunc\left(\frac{k_u - 1}{n}\right) \times t_I(c) + t_l(p_j)$$

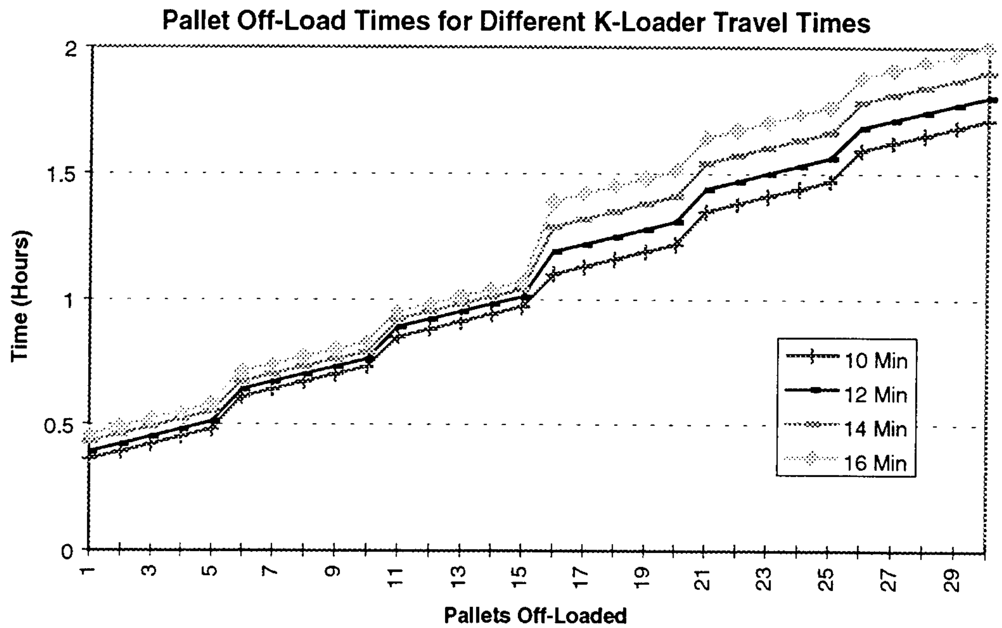
$$t_I(c) = \max\{0, t_d(c) - (n-1) \times t_l(c)\}$$

The first term (t_t) of the delay equation indicates the time between obtaining the k-loaders and the time when the k-loaders arrive at the plane and set up for the first time. There are a total of $k_u - 1$ full pallet loads during the operation, each of which utilizes the full capacity of the k-loader. If the aircraft obtains more than one k-loader, then after all of the k-loaders remove the first set of pallets from the plane, the plane may sit idle for $t_I(c)$ time units while they deliver the pallets to the docks. This will happen when the round trip time to the dock is greater than the pallet pickup time times the number of loaders left at the plane. The final term in the time delay equation indicates the service time of the last k-loader while it removes the final pallets from the aircraft.

This can be generalized to the case where the capacities of the captured k-loaders are not equal. The k-loader with the largest capacity will be utilized first due to the priority scheme used to capture k-loaders. The number of group round trips as well as the requirements for the final trip to the plane for each k-loader can be computed from the capacities of the k-loaders and the requirement of the aircraft. The round trip to the docks will take different amounts of time for the k-loaders, thus the delay between subsequent sets of k-loader missions t_I, if any, will have to be calculated appropriately. A complication may occur if due to differences in delay times, two k-loaders return for their second mission to the plane in the opposite order in which they serviced the plane during the first mission. This can only occur if the difference in time required at the docks is greater than the total time required for the second k-loader to remove a full load of pallets from the aircraft, an unlikely occurrence.

The loaders captured by the aircraft for the off-load operation will not be available for service until after they deposit the last load of pallets at the docks and return to the k-loader holding area of the airfield. Therefore, the resource remains unavailable for a longer time than was required for the aircraft to obtain the service.

Implementing this equation in place of the off-load operation in BRACE resulted in an exact match of off-load delay times as seen by the aircraft in the case of unconstrained cargo resources (k-loaders, dock space, and forklifts). The following graph shows the delay time as a function of the number of pallets being off-loaded from the aircraft for four different k-loader travel times.

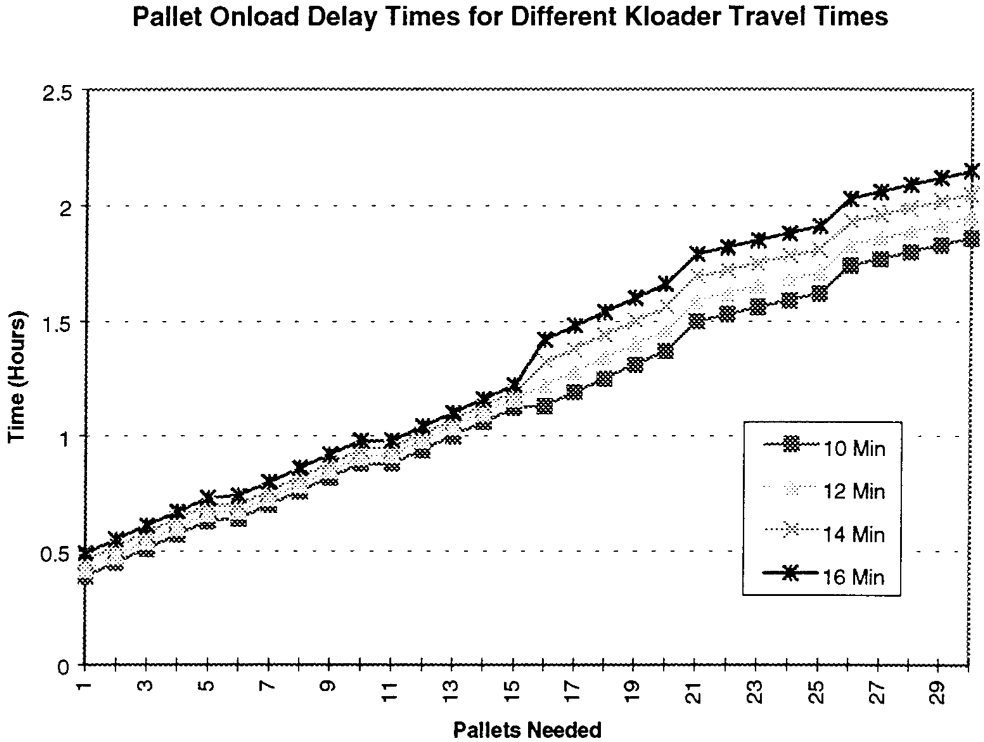


The jump in delay times between a requirement of five and six pallets is caused by the need for a second k-loader. The second k-loader must position itself at the aircraft door before removing the sixth pallet, thus causing the extra time delay as seen by the aircraft. For a requirement of 16 pallets, the three k-loaders captured do not have the capacity to remove all of the pallets in one mission, thus one k-loader must return to the aircraft to remove the final pallet. Here, the extra delay is a function of the travel time of the k-loaders, with a longer idle time delay ($t_I(5)$) for the cases with longer travel times for the loaders. For the shortest travel times, the first k-loader returns to the aircraft quickly enough such that the idle time is zero and only the normal setup time is seen.

Pallet On-Load Operation

The time delay required to load pallets onto an aircraft (T_l^p) can be developed in a similar manner. In the on-load case, the k-loaders travel to the docks to pick up pallets before traveling to the aircraft to load the pallets. Therefore, the aircraft experiences a delay before service equal to the travel time of the k-loaders plus the time required to load the k-loaders at the docks. The k-

loader that picks up the least amount of pallets at the docks will require the least amount of time and thus reach the aircraft first. The following graph shows the delay time as a function of the number of pallets being loaded onto the aircraft for four different k-loader travel times.



Notice the nearly identical delay times in the cases of on-load requirements of five and six pallets. In the five pallet case, a second k-loader is required to pick up just one pallet from the docks and deliver it to the plane. This loader is able to deliver the pallet to the plane and get out of the way before the first k-loader retrieving a full five pallet load has received its pallets and traveled to the plane.

Refueling Operation

For the refueling operation, each aircraft has the opportunity to use either the in-ground hydrant refueling system or fuel trucks which deliver fuel to the aircraft. When the hydrant system is used, the time delay is a function of the fuel flow rate and any delays required to wait for adequate capacity of the fueling system. When using fuel trucks, the delay experienced by the aircraft becomes dependent upon the behavior of the fuel trucks.

When refueling by trucks, one available truck is initially assigned to the aircraft. If more fuel is required than can be supplied by this truck, another available truck is assigned to the aircraft as soon as the first truck completes the transfer of fuel. Using notation similar to the cargo loading procedure, the following variables are needed to compute the fueling delay as seen by the aircraft.

- $f =$ total gallons of fuel needed by the plane
- $c =$ fuel capacity of each fuel truck
- $t_t =$ one-way travel time for a fuel truck
- $t_p =$ time to setup the fuel truck at the plane
- $r =$ fuel delivery rate
- $k = ceil(f / c) =$ the number of full fuel trucks required to fully fuel the aircraft

The aircraft must wait for each required fuel truck to travel to the plane, set up, and then dispense the proper amount of fuel. For the first ($k-1$) fuel truck loads of fuel, the fueling time is (c / r), the capacity of the truck divided by the fuel delivery rate. For the final fuel truck, the delay time depends upon the amount of fuel still required by the aircraft. Thus, the truck refueling delay (T_f), is as follows

$$T_f = t_t + k \times t_p + (k-1) \times \left(\frac{c}{r}\right) + 1 \times \left(\frac{f-(k-1)\times c}{r}\right) = k \times (t_t + t_p) + \left(\frac{f}{r}\right)$$

Simulation Results

A simulated pallet movement operation requires the coordination of aircraft, k-loaders, docks, and forklifts which clear pallets from the docks to the cargo yard. Replacing the entire movement operation with the time delay developed above results in a significant decrease in computational time for the simulation. In one test case where each aircraft required five k-loader loads of pallets, a 500 aircraft simulation ran faster by a factor of eight with the time delay function replacing the pallet on-load part of the simulation.

The equations developed accurately capture the time delay as seen by an aircraft for loading and fueling service at an airfield. They do not, however capture any delay times that would occur if an aircraft was to wait in a queue for available servers (k-loaders or fuel trucks). For this reason, the equations are only used in the place of simulation during situations when the available resources are not being taxed. If there are not adequate available resources, the aircraft wait in a queue as normal and receive fully simulated service. When the equations are used, the appropriate servers are captured to accurately reflect the load on the resource pool. When the service time has expired, these servers are released to become available for other aircraft.